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14. ABSTRACT
The control of low frequency sound into launch vehicle payload fairings remains an important AF problem. The past few years of the project have demonstrated the high potential of using smart foam blankets for efficiently reducing the interior sound levels in the payloads of launch vehicles in the low frequency region where standard blankets perform poorly The approach investigated at VAL consists of a hybrid active-passive approach in which active tile elements are embedded into the conventional passive blanket treatment to improve its low frequency performance. The smart blanket or skin is designed to cover extended regions of the structure through which most of the acoustic power transmits. It functions by reducing the radiation impedance that the structure sees (effectively de-couples the structural motion from the acoustic field) without having to apply control forces directly to the structure itself. The smart skin approach is thus suitable for very stiff structures such as a typical payload fairing. The previous work of the project has demonstrated the potential of a single smart foam tile element. This presentation summarizes recent work focused on extending the system to multiple smart foam tiles applied to a fairing like structure.

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Final Performance Report

On

AFOSR Grant No: F49620-02-1-0184

CONTROL OF SOUND RADIATION AND REFLECTION WITH ADVANCED SMART FOAM BLANKETS

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ABSTRACT

The control of low frequency sound into launch vehicle payload fairings remains an important AF problem. The past few years of the project have demonstrated the high potential of using smart foam blankets for efficiently reducing the interior sound levels in the payloads of launch vehicles in the low frequency region where standard blankets perform poorly The approach investigated at VAL consists of a hybrid active-passive approach in which active tile elements are embedded into the conventional passive blanket treatment to improve its low frequency performance. The smart blanket or skin is designed to cover extended regions of the structure through which most of the acoustic power transmits. It functions by reducing the radiation impedance that the structure sees (effectively de-couples the structural motion from the acoustic field) without having to apply control forces directly to the structure itself. The smart skin approach is thus suitable for very stiff structures such as a typical payload fairing. The previous work of the project has demonstrated the potential of a single smart foam tile element. This presentation summarizes recent work focused on extending the system to multiple smart foam tiles applied to a fairing like structure.

1. OBJECTIVES

The reduction of low frequency sound transmitted in launch vehicle payload fairings remains a challenging technical problem for AF needs. Conventional acoustic abatement blankets have proved unsatisfactory in the low frequency region (below 250Hz) and this has negative effects on the payload such as sonically induced fatigue to the sensitive instruments that are usually carried. Increased noise reduction by increasing the weight and size of the present blanket treatment is not possible due payload weight and size restrictions. The main objective of the work summarized in this presentation is to develop and demonstrate a new technology of "smart" acoustic blankets that have significantly improved low frequency performance without the weight and size penalties that would occur if conventional blankets were modified for the same goal. The smart blanket concept is based upon a hybrid active-passive approach in which active elements are embedded in the standard acoustic blankets in order to increase their low frequency sound transmission loss. In order to achieve this overall goal it will be necessary to investigate and develop a number of component technologies. Suitable active elements will have to be investigated and designed to be embedded in the acoustic blankets. Active control approaches applicable to the high transducer count control system that will result from the extended treatment of the smart blankets will have to be developed and tested. Control sensors that simplify the control arrangement and increase its robustness will also have to be studied. The component technologies will be then be integrated into a compact, lightweight smart blanket treatment. Realistic systems consisting of multiple tiles will be constructed and tested. Finally, the potential of the new smart blanket treatment will be demonstrated on candidate test structures representative of a payload fairing dynamics.

2. STATUS OF EFFORT

2.1 Concepts and analytical modeling.

A smart skin is a novel noise control approach originally conceived and developed at VAL [1]. The smart skin is designed to completely cover radiating structures or extended regions through which most of the acoustic power transmits [1,2,3]. The smart skin is designed to function by reducing the radiation impedance of the structure over a large area with a resultant drop in radiated power. Since the skin only acts on the radiation field it does not require control inputs into the structure and is thus suitable for very stiff structures such as payload fairings. In the following investigation we have taken the physical basis of the VAL smart skin approach and applied it to the payload fairing problem in a unique configuration. The payload application has unique aspects such as very low frequency sound, extremely high level of acoustic excitation and a broadband random frequency content of the excitation. In addition the payload structure is very stiff. This has necessitated investigating and developing novel forms of the smart skin (blanket) and associated control approaches and systems. The following investigation concentrates in the low frequency region (below 250Hz) where the conventional passive blankets have prove to be ineffective [4].

Figure 1 shows a schematic of the smart skin positioned over a section of the payload fairing structure. The smart skin consists of active tiles embedded in acoustic foam (not shown for clarity). The acoustic foam provides the high frequency passive attenuation while the active tiles provide the low frequency active control of the transmitted sound. Figure 2 shows a schematic of an individual tile element. The tile element consists of a lightweight, very stiff panel connected to the payload fairing base structure by active actuators that consist of a spring-damper with an active force applied in parallel to each mount. The active tile is embedded in the acoustic foam in order to control high frequency sound transmission and increase cavity absorption respectively.

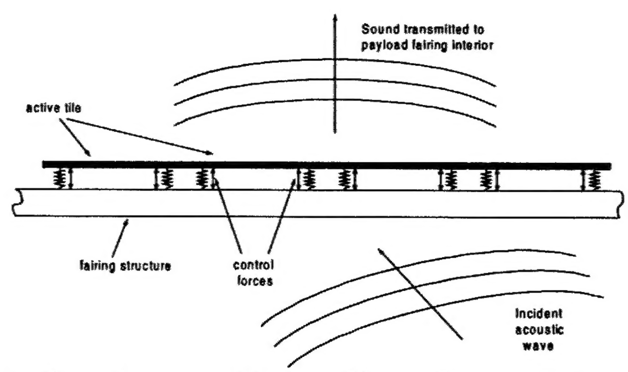

Figure 1. Generic smart skin for plf sound transmission control.

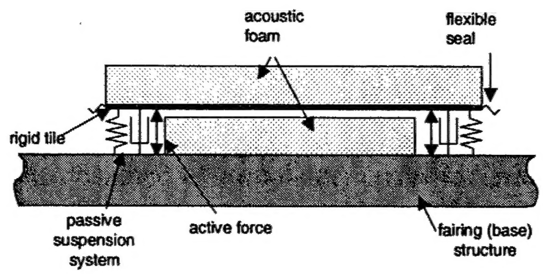

Figure 2. Smart active-passive tile arrangement.

As the tiles are very stiff they do not have flexible response and only have rigid body motion at low frequencies (well below their fundamental bending resonance). Since the tiles are rigid they radiate sound like individual pistons and the sound transmitted to the fairing interior is directly proportional to the tile normal displacement. The arrangement is thus a variation of a classic vibration isolation problem [5]. The active forces thus compensate for the high transmissibility at the mount resonance. Previous work has shown the rocking mode to be insignificant in terms of sound transmission [6]. Reducing the normal displacement of an array of tiles will thus result in a drop of transmitted sound power to the fairing interior.

In this year of work an analytical model of a single active tile has been constructed. The theoretical model consists of a double panel partition consisting of a clamped aluminum base plate covered with a stiff active tile. The tile is mounted on the base plate using isolation mounts with passive spring-damper elements and active forces in parallel. The base plate, which models a fairing section, is acoustically excited by a plane wave. Performance is evaluated from the total acoustic power radiated from the covering active tile. The analytical approach is based upon a mobility-impedance matrix approach in which the system is divided into individual components of base plate, the transmitting system of the isolation mounts and enclosed air cavity and the top plate. The dynamics of each system component is modeled using point and transfer mobilties and is coupled in a matrix system of equations by applying appropriate boundary conditions at each interface. At this stage of the work the effect of the surrounding acoustic foam has not yet been considered.

Figure 3 shows an example simulation result for a single tile with both feedforward and feedback control applied to the active forces. As is expected the passive mounts provide reasonable passive attenuation above the mount system resonance frequency. The use of feedback control to minimize the tile vibration leads to good reduction in transmitted sound around the mount system resonance frequency. The feedforward control of tile vibration is predicted to provide very good broadband control over a very wide frequency range. In summary the feedforward control approach appears to have the best potential. However its use in practice is limited by access to a causal reference signal and expense of the digital hardware.

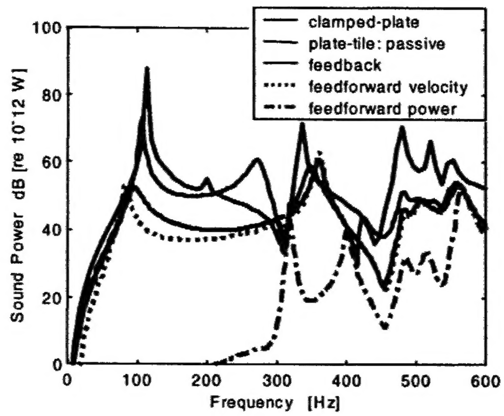

Figure 3. Predicted performance of a single tile

2.2 Experimental testing of a multiple tile set up.

Previous experiments have studied a single tile. Here we report work of this year on a multiple tile arrangement. Figures 4 shows a schematic arrangement of the multiple tile set up while Figure 5 is a photograph of the test rig. The base plate consists of a 3m by 2m aluminum panel, which is 4mm thick. The panel dimensions and thickness was chosen to have similar modal response and stiffness as a typical payload structure. The base plate is covered with four active tiles and acoustically excited by a plane wave at the bottom surface. The active tiles consist of four lightweight and very stiff Nomex panels suspended on sixteen, two per tile, Thunder active-passive mounts as discussed in previous progress reports. Rubber gaskets are used to seal the air gaps between tiles and minimize cross coupling. For the tests reported here the active tile was not yet embedded in the foam blanket material. The tile normal vibration was measured at a number of points by a laser vibrometer and used in conjunction with a Rayleigh integral to estimate sound power radiation.

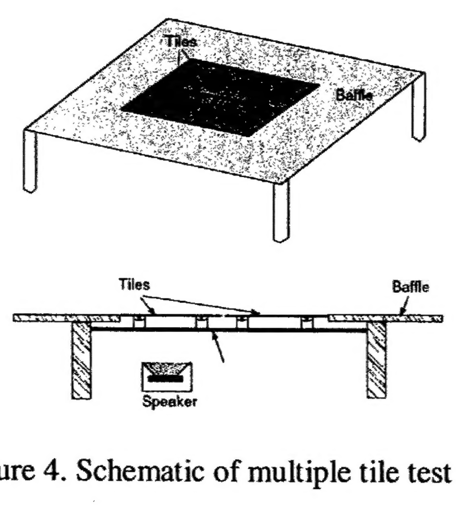

Figure 4. Schematic of multiple tile test rig

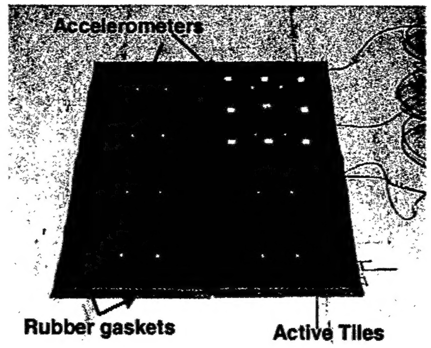

Figure 5. Photograph of multiple tile test rig

Two different control approaches were investigated. The first consisted of feedback loops closed around each active mount and minimizing the vibration of an accelerometer centrally located on each tile. The two mounts were treated as a single channel of control. The control compensator was designed by using a loop shaping process and implemented using analog electrical components. Figure 6 presents typical experimental results for the feedback system. The passive isolation effect of the tile mounts is seen to provide good broadband attenuation. When the active is turned on, increased sound attenuation is observed near the tile-mount resonance frequency. These results are similar to that predicted by the analysis.

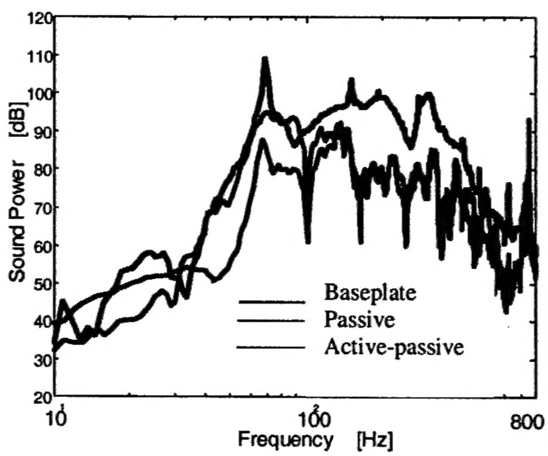

Figure 6. Performance with a feedback control system

The second control approach utilizes a feedforward LMS paradigm implemented on a TI 40 DSP system. In this arrangement four accelerometers were located centrally under each tile and used a reference signals. Four accelerometers were centrally located on each tile and used as error signals. A typical experimental result is shown in Figure 7 and again good passive and active performance is indicated with significant broadband attenuation of the transmitted sound power obtained over a wide frequency range. Results of this years work were presented at Active 2002 in Southampton, Great Britain [7].

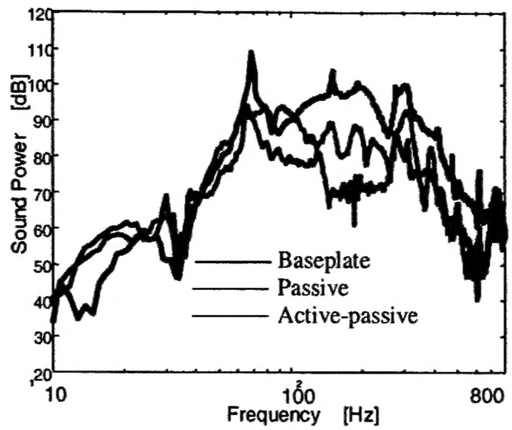

Figure 7. Performance with a feedforward control system

2.3 References

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2. Gentry, C.A., Guigou, C. and Fuller, C.R., "Smart Foam for Applications in Passive/Active Noise Radiation Control", Journal of the Acoustical Society of America, Vol. 101(4), pp. 1771-1778, 1999.
3. Fuller, C. R, Guigou, C. and Johnson, B.D. "Control of Sound Radiated from Structures Using Active Skins', Proceedings of Ibero-American Congress of Acoustics, 18th SOBRAC Meeting, Santa Catarina, Brazil, Vol. 1, pp.186-197, 1998.
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3. ACCOMPLISHMENTS/NEW FINDINGS

Analytical and experimental testing has successfully demonstrated the high potential of a multiple active tile approach for reducing sound transmission into payload fairings. The tile system was found to provide additional noise reductions of 8-10dB over the 50 to 250Hz bandwidth. While a feedforward control approach provides the best broadband performance, an analog feedback system also provides acceptable performance in a system with reduced complexity and cost.

4. PERSONNEL SUPPORTED

Andre Goldstein, Ph.D. Graduate Student
Dr. Mike Kidner, Research Associate
Dr. Chris Fuller, Professor and project PI

5. PUBLICATIONS

Goldstein, A. and Fuller, C.R., 'Control of Sound Transmission with Passive-Active Tiles", Proceedings of Active 2002, pp. 547-558, Southampton, Great Britain, 2002.

Fuller, C. R., "Smart Skins for Sound Control," Volume 2, pp. 1029-1037, The Encyclopedia of Smart Materials, John Wiley and Sons, Inc., October, 2001.

C. R. Fuller, "Active Control: Feedforward Control of Vibration," Volume 2, pp. 513-520, The Encyclopedia of Vibrations, S. G. Braun, D. J. Ewins and S. S. Rao, Editor, Academic Press, September, 2001.

6. INTERACTIONS/TRANSITIONS

a. Participation/presentations at meetings, conferences, seminars

Fuller, C. R., and Elliott, S., "Recent Developments in Active Control," *Plenary Lecture* to INTER-NOISE 2002, Dearborn, MI, August 19-21, 2002.

Fuller, C. R., "Active Control of Sound Radiation from Structures: Progress and Future Directions," *Plenary Lecture* to ACTIVE 2002, p. 3-28, Southampton, UK, July 15-17, 2002.

Fuller, C. R., "Active-Passive Control of Sound with Smart Skins," *Keynote Address* to the 8th AIAA/CEAS Aeroacoustics Conference and Exhibit, Breckenridge, CO, June 17-19, 2002.

Goldstein, A. and Fuller, C. R., "Control of Sound Transmission with Active-Passive Tiles," Presented at ACTIVE 2002, Southampton, UK, July 15-17, 2002.

Fuller, C. R., "Active Control of Sound Radiation from Structures – Progress and Future Directions," presented at The Boeing Company, February, 21, 2003.

b. Consultative and advisory functions

None

c. Transitions

Throughout the past year there has been a strong coordination with Phillips Laboratories at Kirtland Air Force Base (POC: Dr. Steve Lane) and Boeing Space and Communications, Delta IV program (POC: Dr. Haisam Osman). This has involved regularly establishing AF and industry needs for the launch vehicle noise control

application and transmitting of the research program results. Future cooperation on a sounding rocket flight test of the technology has been discussed with the AF. Future cooperation with Boeing S&C will involve testing the smart tile approach on the Boeing composite payload cylinder.

7. NEW DISCOVERIES

None

8. HONORS/AWARDS

None